COMPOSITIONAL SIMILARITIES AMONG MARTIAN METEORITES, REGIONAL GAMMA RAY DATA, AND IN SITU LANDER MEASUREMENTS: IMPLICATIONS FOR IGNEOUS PROCESSES.

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Introduction: There is a growing amount of remotely sensed, in situ, and sample data available to provide information for interpreting processes that shaped the martian surface as well as the planet's interior. These data are derived from six rover and lander missions, the Mars Odyssey Gamma Ray Spectrometer, and a suite of martian meteorites (approx. 110 named stones) [1-10]. The martian meteorite suite (e.g. shergottittes-nakhlites-chassignites, as well as the older cumulate orthopyroxenite ALH84001, and breccia NWA 7034) represents crystallization products of mantle derived basaltic magmas. As such, the chemical and mineralogical variations in the suite reflects their mantle source regions, conditions of martian basaltic magmatism and post-magmatic processes in the crust and surface of Mars.

In order to compare the meteorite data with GRS and lander data, additional data is needed to correct the GRS data for volatile elements including water and contributions of S and Cl from volcanic aerosols. The MSL mission will help provide data for this pupose, and for understanding surficial alteration processes. Additional clues to the later alteration events may also come from the extensive analysis of thermal infrared spectra from the OMEGA instrument on Mars Express, and the CRISM instrument on Mars Reconnaissance Orbiter. For example, the observation of clay minerals in large impact craters may be due to impact hydrothermal processes or alteration within the crust [11].

Integrating the martian meteorite suite into a global and regional context will elucidate (1) the role they played in the growth and evolution of the martian crust, (2) their importance in reconstructing primordial martian differentiation and mantle evolution [i.e. 12], and (3) a mineralogical and chemical starting point for reconstructing surface processes (e.g. weathering, alteration).

Ca/Al Comparisons: Figure 1 shows the relative abundances of calcium and aluminum of rocks and soils, SNC meteorites thought to be representative of melt compositions, the new martian meteorite NWA 7034, and gamma ray regional data (global GRS data has been statistically separated into regions by Karunatillake et al [14]). Data for each set plots in the same area, forming general locations of Ca/Al ratios for different sample groups. The most noticeable trend in the aluminum concentrations is that the SNC meteorites are Al-depleted and the GRS data are Al-enriched, while the landing site analyses and NWA 7034 show Al concentrations in intermediate ranges. Preliminary data from Mars Science Laboratory [15, 16] suggest that at least some of the basaltic rocks from Gale Crater are also Al-rich. As far as calcium concentrations go, the SNC meteorites show the biggest range in calcium concentrations (4.5-14.7 wt %), while all other measurements lie between 3.9 and 7.6 wt % Ca. Before in situ analyses of rocks and soils were conducted on Mars by APXS onboard the Mars Exploration Rovers, SNC meteorites were the only testable record of elemental abundances on the martian surface. The clear discrepancy between the aluminum abundances of the landing site samples and SNC meteorites may be exaggerated due to poor detection of Al by the GRS [13]. It is important to note the Ca/Al ratio of NWA 7034 relative to those ratios of the landing site rock and soil analyses; NWA 7034 is the only meteorite to have similar composition to the current martian surface compositions from the surface missions.

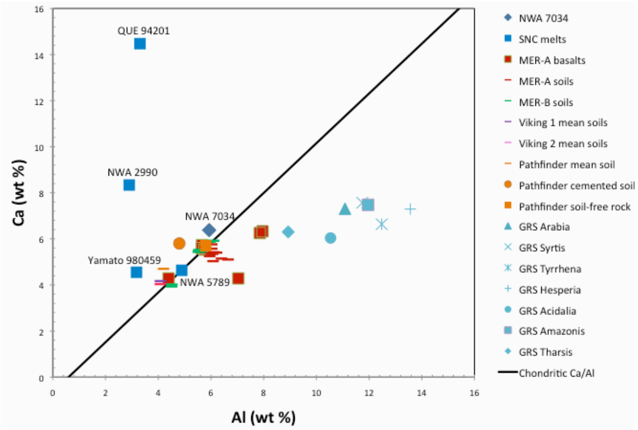

Fig. 1. Viking, Pathfinder, MER A & B, and GRS data plotted with SNC melt compositions (labeled on plot) as well as the composition of NWA 7034. Black line is chondritic Ca/Al ratio, showing superchondritic Al values for the GRS data and superchondritic Ca values for the majority of the SNCs. GRS points have large uncertainties (not shown) due to the large gamma-ray footprint and poor counting statistics.

Mg/Al Comparisons: Figure 2 shows the Mg/Si vs. Al/Si variation in the samples discussed in Figure 1 (excluding GRS data due to poor detection of Mg and Al). The black terrestrial fractionation line [18] and red shergottite fractionation line [19] have been used to distinguish between terrestrial and martian origins for rocks, but if rocks are cumulates their accumulated characteristics will show through in this plot [20]. The

SNC compositions plot on or near the martian fractionation line, lending credibility to their being representative of magmatic liquids, while NWA 7034 and most of the in situ analyses of rocks and soils plot closer to the terrestrial fractionation line. The Pathfinder soil-free rock and Viking 1 & 2 mean soils plot along the martian fractionation line.

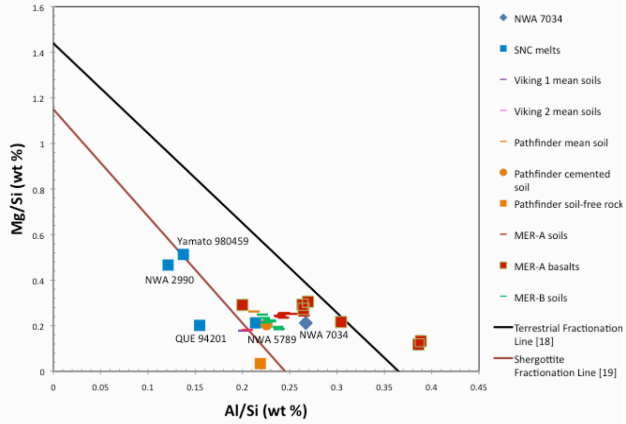

Fig. 2. Samples from Fig. 1 (except GRS data) plotted on a typical classification plot used to distinguish primitive terrestrial rocks from primitive martian rocks.

Th as Indicator of LREE Enrichment: A meteorite's inventory of REE's can give insight into its source region. Depleted shergottites will have a chondrite normalized La/Yb ratio around 0.1, and are thought to originate from a depleted, mostly-unaltered source region. Enriched shergottites have normalized La/Yb values around 1.5, and may have formed from either an enriched crust or mantle source or a source that has undergone mixing of a depleted and enriched component [21]. We have compared LREE enrichment with Th abundance in martian meteorites to see if a correlation exists. If there is a correlation, it may be extrapolated to the GRS data to match melt compostions to regional sources of varying degrees of LREE enrichment. Plotted in Figure 3 are the Th concentration in ppm versus the relative LREE enrichment (La/Yb) of each meteorite from the previous figures, as well as enriched shergottites [8, 10]. LREE-depleted SNCs have similar Th concentrations, but the enriched meteorites (NWA 2990, NWA 7034, and the shergottites) have different Th concentrations. If NWA 7034 is confirmed as being respresentative of a melt composition, a positive trend could be fitted to find a correlation between Th concentration and LREE enrichment of a meteorite. The potential of a Th-LREE enrichment trend differs from the non-correlation seen in the concentrations of phosphorus, showing the variability of the partition coefficients of garnet in the SNCs [24]. Further study to find a correlation between LREE enrichment and a (preferably GRS-detectable) non-REE elemental concentration in martian meteorites may be a helpful tool in linking SNC and other martian melts with their region of origin on the martian surface.

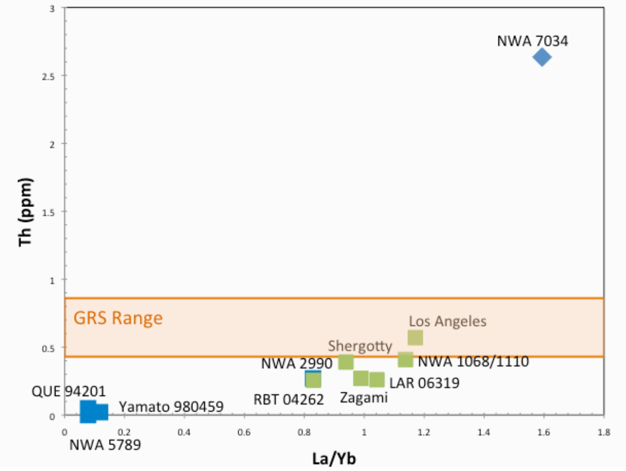

Fig. 3. Th vs CI-chondrite normalized La/Yb for NWA 7034 (blue diamond) and other enriched shergottites (melts are blue squares, others are green squares).

Conclusions: Access to information concerning the composition of the martian surface has increased greatly since the landing of the MSL Curiosity rover lin August 2012 and the discovery of the NWA 7034 meteorite. The ChemCam and APXS instruments are contributing elemental data from yet another landing site on Mars, allowing for more constraints on regional and global surficial chemistry [15, 16]. Using the new data from MSL, as well as refining the Odyssey GRS data to better coincide with in situ measurements, will contribute to better understanding surface processes and igneous formation of Mars.

References: [1] Clark B. C. et al (1982) *JGR, 87,* 10059-10067. [2] Newsom H. E. et al (2007) *JGR, 112,* E03S12. [3] Yen A. S. et al (2005) *Nature, 436,* 49-54. [4] Geller R. et al (2004) *Science, 305,* 829-832. [5] Bruckner J. et al (2003) *JGR, 108,* 8094. [6] Gellert R. et al (2006) *JGR, 111,* E02S05. [7] Ming D. W. et al (2008) *JGR, 113,* E12S39. [8] Meyer C. (2012) *Martian Meteorite Compendium*. [9] Filiberto J. and Dasgupta R. (2011) *EPSL, 304,* 527-537. [10] Agee C. B. et al (2013) *Science,* DOI:10.1126/science.1228858. [11] Ehlmann B.L. (2009) *JGR, 114*, E00D08. [12] Agee C. B. and Draper D. S. (2004) *EPSL, 224,* 415-429. [13] Boynton W. V. et al (2004) *Space Science Reviews, 110,* 37–83. [14] Karunatillake S. et al (2009) *JGR, 114,* E12001. [15] Newsom H. E. et al (2013) LPSC. [16] Wiens R. C. et al (2012) AGU. [17] Elkins-Tanton L. T. et al (2003) *Meteoritics & Planetary Sci., 38,* 1753-1771. [18] Jagoutz E. et al (1979) LPSC. [19] Wänke H. et al (1984) *Lunar & Planetary Sci., XVII,* 919-920. [20] Filliberto J. et al (2006) *Am. Mineralogist, 91,* 471-474. [21] McCubbin F. M. et al (2012) *LPSC.*